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The Multifunction Automated Crawling System (MACS)

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Abstract

A new robotic crawler is being developed for inspection of large aircraft external surfaces. The Multifunction Automated Crawling System (MACS) has been designed and fabricated to carry miniature instrumentation to perform a wide variety of tasks while being attached to an aircraft's surface. The immediate application of MACS is inspection of the exterior of large military aircraft such as the C-5. Various inspection payload modules can be incorporated onto the MACS crawler to perform the desired inspections. MACS employs ultrasonic motors for mobility and suction cups for surface adherence. MACS has two legs for linear motion and a rotation element for turning, enabling any simultaneous combination of motion from linear to rotation about a central axis.

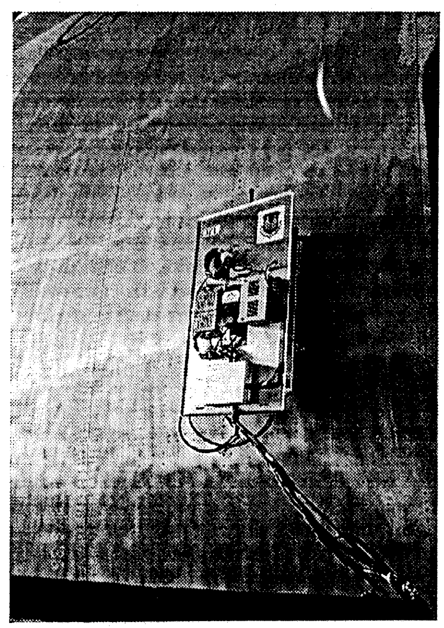

Figure 1: Closeup view of MACS-I on a C5

1. Introduction

Regular inspection of aircraft is critical to ensure their safety and to determine when repairs are needed. Aircraft inspection can be both time consuming and difficult to perform due to structural complexity, the size of aircraft, such as external inspection of the C-5, and due to difficult access, such as internal engine and fuel tank inspection and inspection behind panels.

Inspection is becoming increasingly important as military aircraft are being used in service significantly longer than their original design life. This cost driven measure is subjecting the structures of these aircraft to conditions that are increasing the probability of failure, particularly as a result of aging. An example of such aircraft is the KC-135 which has already endured a long service life of about 35 years and is now being considered for another 45 years of service.

Military aircraft are routinely exposed to service conditions that lead to the degradation of the quality and performance of their structural materials. This degradation is costly and can cause a catastrophic loss if left undetected, requiring periodic maintenance to assure both the residual life and the protection of the structure. The factors that can cause structural degradation are extensive static and cyclic mechanical and thermal loads, humidity, exposure to extreme high or low ranges of temperatures, impulse loading including impact damage (flying debris, hail, rain,

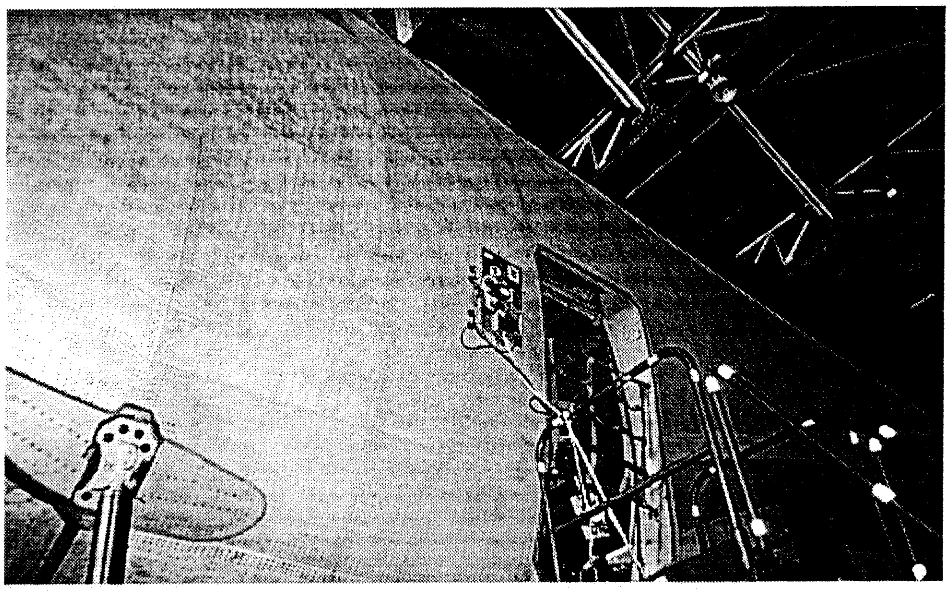

Figure 2: MACS-I on a C5

etc.), thermal spikes, service fluids (fuel, grease, acid rain, urine, cleaning chemicals, etc.), radiation damage (UV, radioactive) and erosion (dust, ash).

There are two primary types of flaws to detect during inspection: corrosion and cracking. Corrosion is a general term for the oxidative degradation of metals and can appear in many forms, depending on the metals that are involved and the damage mechanism. There are three basic types of cracking: fatigue cracks, bending cracks, and stress corrosion cracks.

The trend to increase the usage of aging aircraft has increased the need for low-cost, rapid, and reliable nondestructive evaluation (NDE) methods for detection and characterization of flaws in aircraft structures. Most inspection systems are hand-held devices with results which depend heavily on the skill and attentiveness of the operator. Portable c-scan bridges can be attached to the aircraft surface to allow automated scanning of the area where they are attached. C-scan bridges have improved the reliability of large area NDE, but the bridge itself is stationary. When a scan is completed at one location, the operator moves the bridge to the next inspection area. More recently, mobile crawlers have been proposed which can carry sensors over the surface of the aircraft [1–4].

This paper describes the Multifunction Automated Crawling System (MACS) which has been developed at JPL to perform large area inspection of aircraft (patent pending [5]). A close-up picture of MACS on a C-5 aircraft is shown in figure 1. Section 2 describes the target application for MACS and section 3 describes the MACS-I system. Section 4 describes the MACS-II and MACS-III designs and discusses future enhancements. Conclusions are given in section 5.

2. Target Application

The MACS prototype is being developed for the San Antonio Air Logistics Center for large area inspection of the exterior of aircraft such as the C-5 and KC-135. Figure 2 shows the MACS crawler on a C-5 aircraft. Currently there are large areas of the aircraft which are difficult to reach by a person due to being very high up on the aircraft such as the upper areas of the fuselage and the tail section. The MACS crawler will be able to crawl on these areas and perform the inspection. MACS will send images and sensor data back to

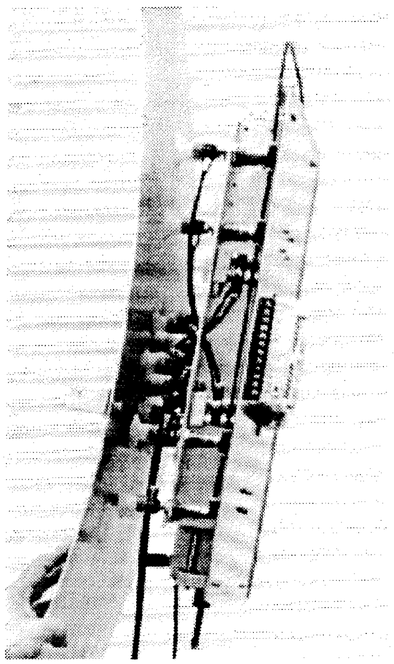

Figure 3: Side view of MACS-I

an operator who could be at the base of the aircraft, in a control room at Kelly AFB, or potentially anywhere in the world. Applications of the MACS crawler include inspection of repairs, composite materials, and structures of aging aircraft, detection of cracks, corrosion, impact damage, unbonds, delaminations, fire damage, porosity and other flaws, paint thickness measurement, perform specific tasks such as identification of dents, and individual fasteners, etc.

3. MACS-I System

The MACS crawler has been designed and fabricated to carry miniature instrumentation to perform a wide variety of tasks while being attached to an aircraft's surface. It combines small size and light weight with improved mobility characteristics. Figures 3 and 4 show side and bottom views of MACS. Development of the MACS crawler is benefiting from leveraging ongoing NASA miniature planetary rover [6], telerobotics [7], and NDE technology development. The leveraged technologies include miniature and lightweight mechanisms and construction materials, ultrasonic motors, on-board computing and intelligence, and miniature sensors.

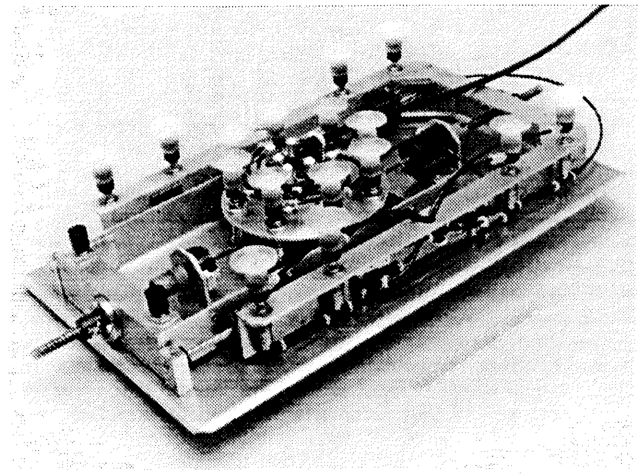

Figure 4: Bottom view of MACS-I

The MACS crawler employs ultrasonic motors for mobility and suction cups for surface adherence. MACS has two legs for linear motion and a rotation element for turning, enabling any simultaneous combination of motion from linear to rotation about a central axis. Figures 5 and 6 show the MACS-I translational motion and combined translational and rotational motion. The mobility of MACS-I is performed with two motors which simultaneously provide the linear motion and a single motor provides the rotation. The rotation motor is connected to the inner leg of the crawler. Any motion from linear to rotation about an internal axis and any combination of these is possible. Low mass, high torque density ultrasonic motors are used. The ultrasonic motor technology is currently being developed for space telerobotics applications. A set of short profile vacuum cups were specially designed for MACS to allow its adherence to the surface while moving. A miniature on-board computer (PC/104 bus, 80486 microprocessor, not shown in the figures) will control the operation of MACS and perform such tasks as imaging, data acquisition, and communication.

The crawler is designed to carry a video camera for visualization, inspection and collision avoidance tasks. Various miniature inspection instruments can be used as payloads of MACS to

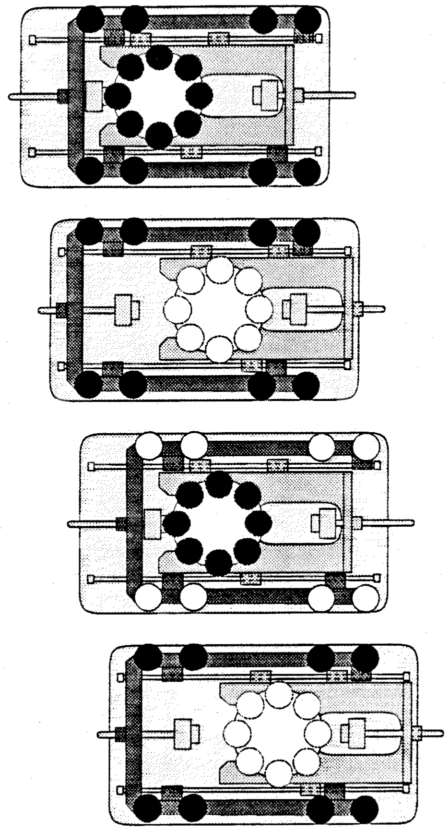

Figure 5: MACS-I translational motion (solid color cups are attached to surface)

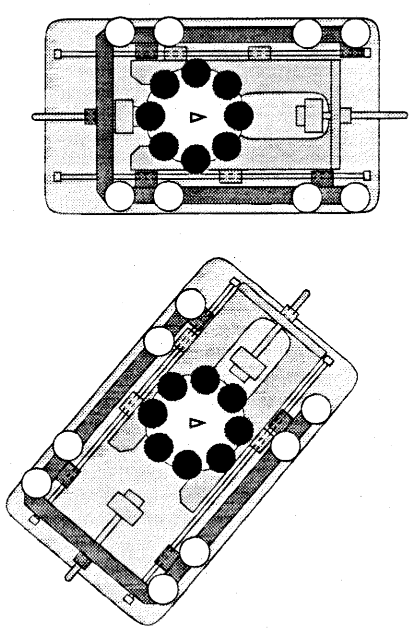

Figure 6: MACS-I combined translational and rotational motion

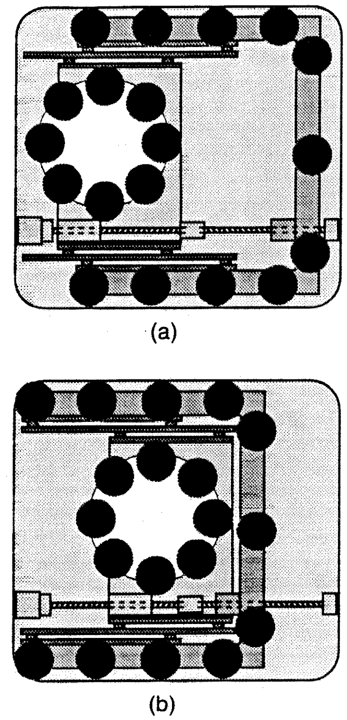

Figure 7: MACS-II in (a) expanded and (b) contracted positions

perform visual, tap testing, eddy current, ultrasonic or other types of inspections.

4. New Designs and Future Enhancements

4.1 MACS-II Design

A more compact version of the MACS crawler, called MACS-II, has been designed. MACS-II has all of the mobility characteristics of MACS-I but with one fewer motors. One translational motor replaces the two translational motors of the MACS-I design. Left and right hand threaded ball screws are connected together and driven by the motor and each is coupled to one of the legs for translational motion. The same rotational motion design is used as for MACS-I. The MACS-II design is shown in figure 7.

4.2 MACS-III Design

A simpler version of the MACS crawler,

MACS-III, was also designed. MACS-III has one fewer translational legs. The suction cups which were attached to the second leg in the MACS-I and MACS-II designs are attached to the platform in the MACS-III design. The functionality difference is that the platform of MACS-III is stationary, attached to the surface, when the leg is not attached to the surface, i.e. when the leg is repositioning for a move. In the MACS-I and MACS-II designs, the platform moved when any leg was moving. The increased simplicity of the design may make this trade-off worthwhile. Translational motion and combined translational and rotational motion of the MACS-III crawler are shown in figures 8 and 9.

4.3 Potential Enhancements

Potential enhancements to the crawler include increased on-board intelligence, tetherless operation, operation over the internet, localization, and integration of multiple sensor payloads. Operation over the internet will enable experts to view the inspection data without having to be where the aircraft is. Increased on-board intelligence will leverage the NASA work on on-board intelligence of miniature Mars rovers. Tetherless operation will require the development of a new lightweight vacuum pump. Operation over the internet will leverage NASA work on World Wide Web based interfaces which allow scientists to view science data and input commands to Mars rovers over the internet, thus allowing them to participate in missions from their home institutions. This is currently done using the Web Interface for Telescience for control of the JPL Rocky7 rover over the internet [6].

5. Conclusions

The Multifunction Automated Crawling System is a small, light weight crawler with advanced mobility characteristics for large area inspection of aircraft external surfaces. The MACS-I laboratory prototype has verified the basic design. The MACS-II and MACS-III refined designs provide alternatives for the two and one leg designs. The

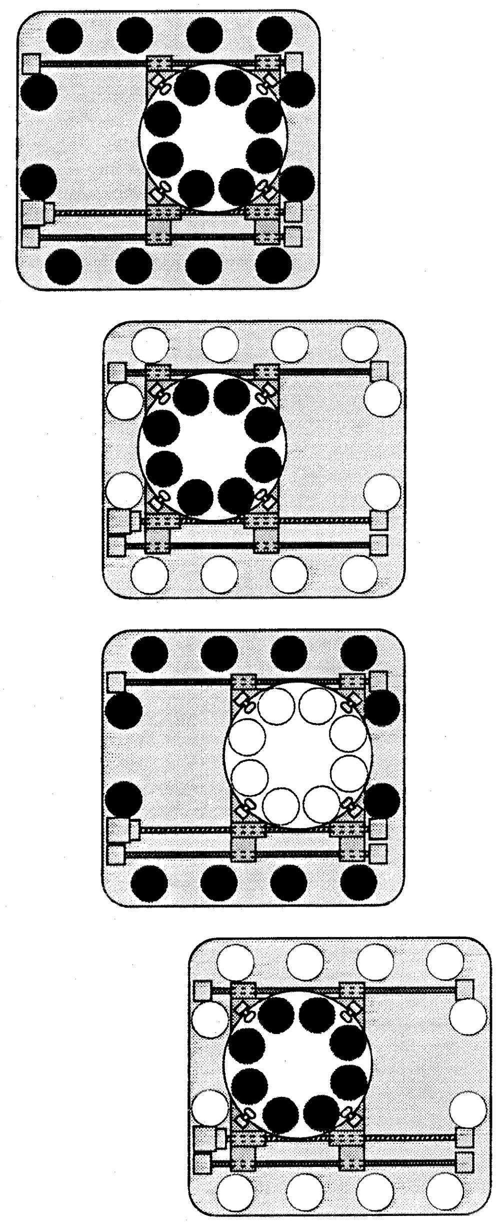

Figure 8: MACS-III translational motion (solid color cups are attached to surface)

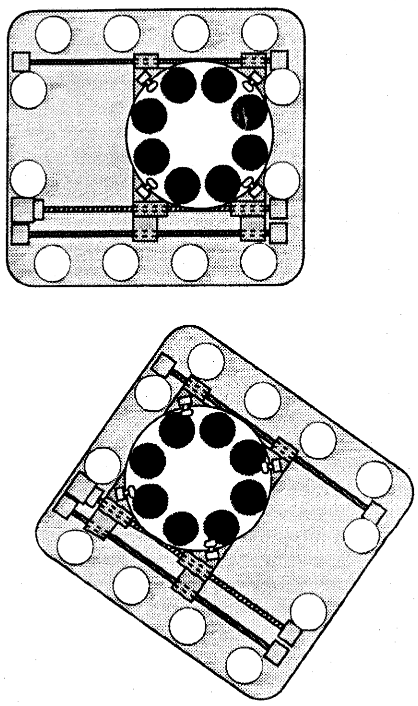

Figure 9: MACS-III simultaneous rotational and translational motion (solid color cups are attached to surface)

MACS crawler will enable improved aircraft inspection by enabling large area inspection without a dedicated facility.

Acknowledgements

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